

# The Production of an All-Waste Steel Slag Alkali Activated Concrete

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**Abstract** - The massive consumption of the major components utilized in the production of ordinary cement based concrete as a construction material, not only affects the environment via the pollution of the cement production but also via reducing the raw materials resources such as the coarse and fine aggregates as well, the condition that will impact the future of the traditional concrete to continue as being the utmost used construction material worldwide. In such regard, and taking into account the world nations concerns regarding the sustainability of the resources, the authors is introducing in this research the production of an all-waste concrete that will be totally prepared all from an industrial by-product which is the steel slag. Different slag types were used to fully replace the fine, and coarse aggregates, beside, the use of ground granulated blast furnace steel slag (GGBFS) as a precursor to the alkali activated binders. Six different mixes were prepared with 4 different alkali activated binder constituents and the optimum out of them were then been compared to a mix containing the same binder but with natural aggregate, and an ordinary Portland cement mix with natural aggregates. The results revealed that the all waste concrete could be a competing alternative to the normal OPC concretes. The optimum all-waste concrete showed a strength gain of almost 30% higher than the OPC concrete.

**Key Words:** Waste, OPC, Steel Slag, compressive strength, GGBFS, alkali activated binder

## 1. INTRODUCTION

Recently, the obvious effect of global warming represented on the climatic change all over the world urges researchers to find urgent solutions to overcome this vital issue. Concrete is one of the most environmental-polluted industry due to the massive amount of CO<sub>2</sub> emissions produced during its manufacturing through cement industry, so finding alternatives for traditional concrete become a necessity in order to reduce the pollution and protect the environment.

recently and via the nanotechnology, the reduction of cement contents have been extensively studied [1-7], but unfortunately other costs has been added to the process due to the difficulty of the nano components utilization including but not limited to the dispersion techniques as the ultrasound sonicators, surfactants, and homogenizers.

Nowadays, Alkali Activated Materials (AAM) consider one of the sustainable cementing binding materials [8-9]. Some

references named AAM as Geopolymer [10]. AAM can produced from different aluminosilicate resources, which differ in their availability, reactivity, and cost. The local availability of the sources of AAM is the main governing discussing point to use AAM. As, most of the elements used in the production of AAM are also used in the production of ordinary Portland cement [11]. On the other hand, AAM sometimes can be relatively inexpensive option compared to using ordinary Portland cement, especially in the sites which are relatively remote and requires Portland cement to be imported [12]. In addition to, the source of the activator can be also a challenging issue in some areas.

Finally, and as concrete is generally contain about three-quarter of aggregate, so it is not surprising that its quality not only has a vital effect on the strength of concrete but also the aggregate properties greatly effects the durability and the performance of concrete. The significant over-utilization of natural resources, mainly dolomite and sand, will result in an adverse effect on the environment.

Therefore, the utilization of by-products plays an important role to preserve the natural resources and helps to promote sustainable development in the protection of natural resources; thus reduces the disposal of such by-product wastes.

This encourage researchers to explore new materials to replace the traditional concrete by a concrete made from by-product materials. Geopolymer concrete and alkali activated materials become nowadays a trend to substitute ordinary concrete beside their comparative properties with respect to normal concrete.

Blast furnace slag is a by-product generated during manufacturing of pig iron and steel and may be defined according to ACI-116R [13] as "nonmetallic product consisting essentially of calcium silicates and other bases that are developed in a molten condition simultaneously with iron in a blast furnace". It consists primarily of silicates, alumina-silicate, and calcium-alumina-silicates. The slag cooling process is mainly responsible for the generation of various types of slag required for different end-users. The physical and pozzolanic properties of slag vary widely with the process of cooling [14-15]. Granulated blast furnace slag is a non-toxic material and can be a good raw material for making high-value and user-friendly cementitious material for different civil engineering applications.

All these factors boost the study and development of new alternative all-waste alkali activated binders with lower environmental impacts (lower CO<sub>2</sub> emissions, reuse of industrial by-products) and performance as high as or higher than ordinary Portland cement (OPC).

## 2. EXPERIMENTAL WORK

### 2.1 Materials:

The alkali-activated slag concretes were made of granulated blast furnace slag and a solution of Sodium silicate and Sodium Hydroxide. Egyptian Ground granulated blast furnace slag (GGBFS) used in this investigation was obtained from the Iron and Steel Company, Helwan, Egypt. Table 1 shows the chemical composition of slag.

The slag was activated by a mixture of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>). They used sodium hydroxide, which is highly soluble in water (in quantity required to reach the target concentration) and the sodium silicate was used in form of a solution. The mass ratio of SiO<sub>2</sub> to Na<sub>2</sub>O in the sodium silicate solution was 2.58. Table 2 shows the chemical composition of both sodium silicate and sodium hydroxide.

**Water Cooled Slag:** Egyptian Ground granulated blast furnace slag (GGBFS) or (water cooled slag) used in this investigation was obtained from the Iron and Steel Company, Helwan, Egypt, Figure 1, The granulated blast-furnace slag is sand-type slag manufactured by spraying high-pressure water jets on a blast-furnace molten slag, the sieve analysis of GGBFS shown in Figure 1.

**Grinded Water Cooled Slag:** Water cooled slag is the main component used in the production of alkali activated mortars after being grinded as shown in table 1.

**Air Cooled Slag:** Egyptian blast furnace slag (BFS) used in this study was obtained from the Iron and Steel Company, Helwan, Egypt, Figure 2, It is produced when iron pellets or iron ore, coke and a flux (either dolomite or limestone) are molten together in a blast furnace. When the metallurgical smelting process is finished, the lime in the flux has been chemically combined with the silicates and aluminates of the ore and coke ash to form a non-metallic product named blast furnace slag. Blast furnace slag is cooled slowly by ambient air. Sieve analysis for coarse slag is shown in Figures 1, and 2.

### 2.2 Mix Preparation:

The binder content was kept constant for all mixes at 375 Kg/cubic meter, and the fine to coarse aggregate ratio was kept to 1:2. Prior to the preparation of the concrete mixes, alkali solution of the desired concentrations was prepared at the room temperature. The Na<sub>2</sub>O concentration was set to 9.5% by weight of total binder and four activator modulus Ms (SiO<sub>2</sub>/Na<sub>2</sub>O) ratios (.8, 1, 1.2, and 1.4) were prepared. The water to binder ratio was kept constant at 0.30. All mixtures

were prepared by mixing the liquid sodium silicate and sodium hydroxide flakes with water in a laboratory beaker until all NaOH flakes dissolved. The temperature and the pH of solution were measured immediately after the mixing, then the solution was added to the binder and mixed for 10 mins. 15 x 15 x 15 cm cubes were used to cast the concrete mixtures. The cubes were demolded after one day and cured in water at a temperature of 20°C to test days. The compressive strength were then been performed after 7, and 28 days of curing. The mix names were as follows:

- Control: representing the OPC + Natural Aggregates mix.
- AABC: Alkali activated binder control mix with natural aggregates.
- AABS0.8: Alkali activated binder with slag aggregates and MS = 0.8
- AABS1.0: Alkali activated binder with slag aggregates and MS = 1.0
- AABS1.2: Alkali activated binder with slag aggregates and MS = 1.2
- AABS1.4: Alkali activated binder with slag aggregates and MS = 1.4

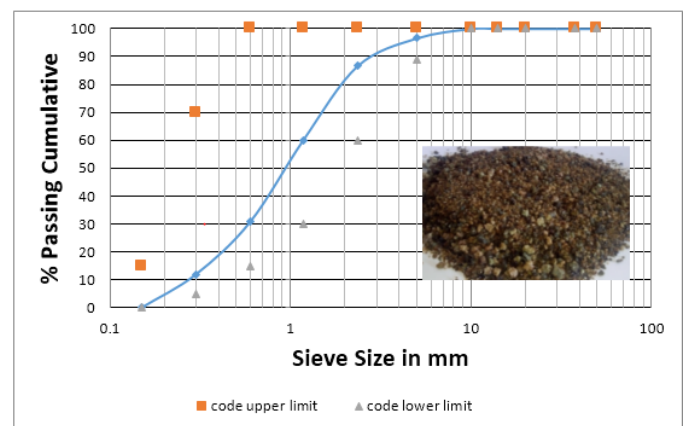


Figure 1: sieve and shape of water cooled slag

Table 1: Chemical composition of GGBFS by XRF

percentage	Constituents
38.25	<u>SiO<sub>2</sub></u>
7.64	<u>Al<sub>2</sub>O<sub>3</sub></u>
34.2	<u>CaO</u>
0.53	<u>Fe<sub>2</sub>O<sub>3</sub></u>
7.73	<u>MgO</u>
1.14	Na <sub>2</sub> O
1.35	<u>K<sub>2</sub>O</u>
3.01	<u>SO<sub>3</sub></u>
0.54	<u>TiO<sub>2</sub></u>
≥ .01	<u>P<sub>2</sub>O<sub>5</sub></u>
5.17	<u>MnO</u>
0.18	<u>Cl</u>
≤ 0.01	Loss on ignition



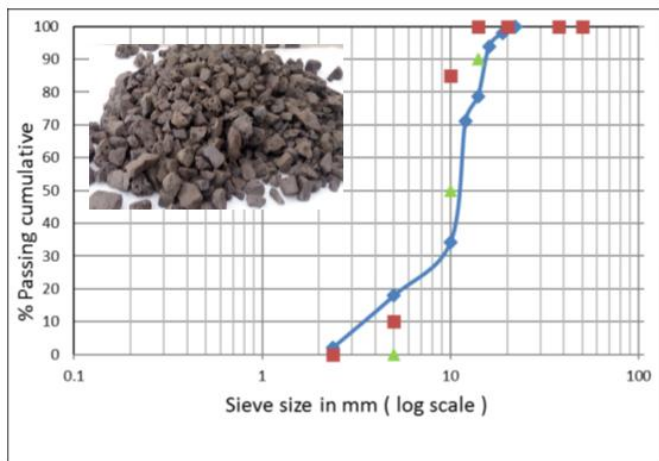


Figure 2: sieve and shape of Air cooled slag

Table 2: chemical composition of Na<sub>2</sub>SiO<sub>3</sub> and NaOH

	SiO <sub>2</sub>	Na <sub>2</sub> O	H <sub>2</sub> O
Sodium Hydroxide (NaOH)	—	60.25%	39.75%
Sodium Silicate (Na <sub>2</sub> SiO <sub>3</sub> )	31%	11.98%	57%

### 3. Results and Discussions:

Based on the conducted experimental plan, the following were reached:

At the first, the PH of all the alkali activated mixtures ere in the range of 11 to 11.5.

The temperature of the activators measured directly prior to mixing for all different MS ratios are presented in figure 3. The effect of MS ratio on the temperature of the activator is highly significant, the highest temperature was equivalent to the lowest MS ratio and vice versa, this could be attributed to the higher content of the Na<sub>2</sub>O at the lower MS, while at the higher MS ratios, the sodium silicate content was increased over the Na<sub>2</sub>O content which resulted in lowering the activator overall temperature. The results of the slump represented in figure 4 also indicates the effect of the sodium silicate content on the workability of the concrete mixtures, the slump values were inversely proportional with the temperature values and in trend with the MS , and Sodium silicate contents.

The slump was also increased slightly for the alkali activated binder mixes over the OPC mix, this could also be due to the lubricating effect of the sodium silicate in the alkali activated mixes.

Generally, increasing the MS ratios increases the 7, and 28 days' compressive strengths just to a certain limit and then it starts to reduces, at the W/B ratio studied (0.30), as shown in

Figure-5, and 6. These results agreed with the results obtained by previous researches [16-18].

The significant increase in the compressive strength of the alkali activated binder mixes as compared to the OPC control mix could be attributed to the positive impact of sodium silicate on the compressive strength as it boosts the compressive strength of alkali activated concrete paste in two ways, firstly sodium silicate solution improves the dissolution rate of Si and Al, and the second way is dissolving Al rapidly in the alkali solution because the Al-O bonds are weaker than Si-O bond in raw material, resulting in enhancing the binding components within the matrix as compared to the OPC hydration binding products. The strength gain for the alkali activated mixes was directly proportion to the MS ratio till a certain level of 1.2, and then a significant decrease occurred at MS ratio higher than 1.2. it was found from previous studies that with increasing MS to a very high level, the temperature of the activator decreases (in our case from 90 degrees to 65 degrees) due to the dilution of the solution after adding more sodium silicate and consequently the compressive strength decreased because the amount of NaOH needed to leach the SiO<sub>2</sub> and CaO from the slag was lowered with the increase in temperature.

The compressive strength was significantly higher for the alkali activated mixes with the slag used as replacement for the fine and coarse aggregates than those contained natural aggregate, this could be due to the roughness of the slag aggregated surface rather than the natural aggregate leading to higher bonding between the aggregate and the alkali activated matrix than with the natural aggregate. Moreover, the alkali activator could also result in enhancing the binding between the slag aggregates and the matrix by the mentioned above leaching process due to the chemical composition and reactivity of slag aggregates, which is alkali reactive and not inert like natural one, resulting in improving the bond between the slag aggregate and alkali activated binders which mean another type of bond at the interface.

Finally, the gain in compressive strength at the late age of 28 days, was almost 30 percent higher for the optimum slag aggregate alkali activated mix as compared to the OPC mix, and about 28% higher as compared with the natural aggregate alkali activated mix.

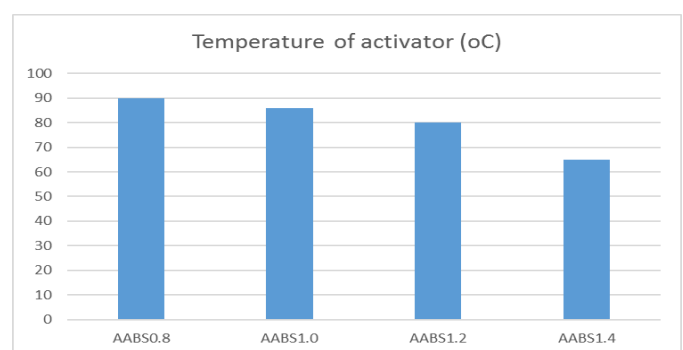


Figure 3: temperature of activators for all mixes

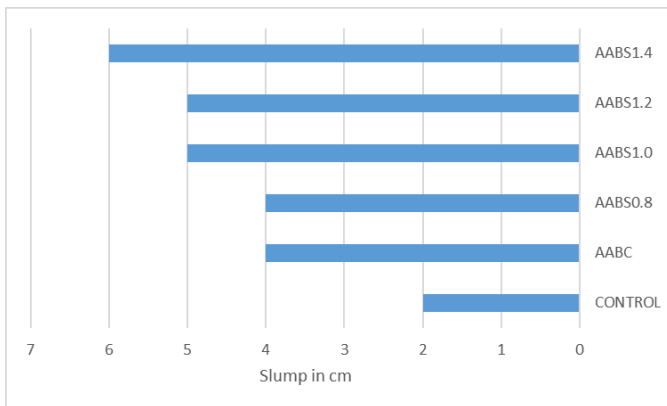


Figure 4: Slump results for all mixes

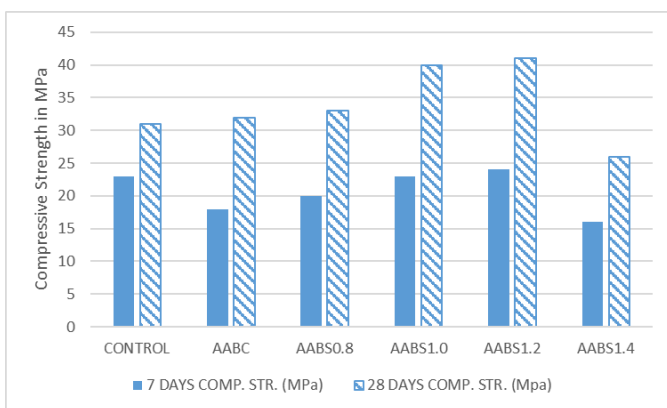


Figure 5: Early and late age's compressive strengths

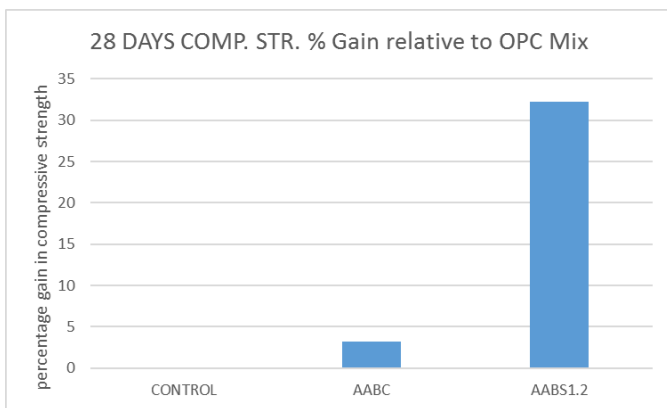


Figure 6: Gain in compressive strength for mixes; Control, ABBC, and ABBS1.2

#### 4. CONCLUSIONS

From the studied parameters and factors, the study revealed that the development of new alternative of all-waste alkali activated concrete mixes with lower environmental impacts and high mechanical properties and with performance as high as or higher than ordinary Portland cement (OPC) is in hand.

Generally it could be concluded that the MS ratio is directly proportional with the workability values, while it has an inverse proportion effect with the activator temperature. As for the compressive strength gain for the alkali activated mixes, it was directly proportion to the MS ratio to the level of 1.2, and then a significant decrease occurred at MS ratio higher than 1.2.

Finally, The gain in compressive strength at the late age of 28 days, was almost 30 percent higher for the optimum slag aggregate alkali activated mix as compared to the OPC mix, and about 28% higher as compared with the natural aggregate alkali activated mix. And the workability of this mix was enhanced as well.

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